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Y Production at CDF

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Υ Production at CDF

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ABSTRACT

We report on measurements of the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ differential and integrated cross sections in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The three resonances were reconstructed through the decay $\Upsilon \rightarrow \mu^+\mu^-$. The cross section measurements are compared to theoretical models of direct bottomonium production.

1. Introduction

We report a study of the reaction $p\bar{p} \rightarrow \Upsilon X \rightarrow \mu^+\mu^- X$ at $\sqrt{s} = 1.8$ TeV. This study yields the P_T dependence of the production cross sections for the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ states as well as the integrated cross sections. This is the first measurement of the individual Υ cross sections at the Tevatron energies and it is important for the investigation of bottomonium production mechanisms in $p\bar{p}$ collisions.^{1,2} Although, due to triggering constraints, we cannot extend our charmonia production cross section measurements below 4 GeV/c, the Υ resonances can be reconstructed with P_t as low as 0. Therefore we can measure the total cross sections as well.

The CDF detector has been described in detail elsewhere.³ Here we give a brief description of the components relevant to this analysis. The central tracking chamber (CTC) is in a 1.4116 T axial magnetic field and has a resolution of $\delta P_t/P_t = \sqrt{(0.0011P_T)^2 + (0.0066)^2}$ for beam constrained tracks. The original central muon chambers (CMU), at a radius of 3.5 m from the beam axis, provide muon identification in the region of pseudorapidity $|\eta^\mu| < 0.61$. These chambers have been complemented by the addition of four layers of drift tubes behind 2 feet of steel (CMP), and as a result, hadronic punch-through backgrounds to the muon signal have been considerably reduced.

1.1. Event selection

The measurements reported here are based on a data sample of opposite sign dimuons collected with a multilevel trigger corresponding to a total integrated luminosity of 16.6 ± 0.6 pb⁻¹. The muons from the $\Upsilon \rightarrow \mu^+\mu^-$ decay were required to satisfy the following criteria: i) both muons were identified by the CMU system and at least one of them was identified by both the CMU and CMP systems; ii) $P_t(\mu) >$

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2.0 GeV/c for each muon; iii) $P_t(\mu) > 2.8$ GeV/c for at least one of the two muons; iv) less than a $(3 - 4)\sigma$ difference in position between each muon chamber track and its associated, extrapolated CTC track, where σ was the calculated uncertainty due to multiple scattering, energy loss, and measurement uncertainties; v) a common vertex along the beam axis for the two muons; region of rapidity of the dimuon pair $|y| < 0.4$. In addition the Level 1, Level 2 trigger had to be satisfied by the dimuon pair. The transverse momentum P_t of the dimuon pairs had to be greater than 0.5 GeV/c and less than 20 GeV/c. The invariant mass distribution of opposite sign dimuon pairs is shown in Fig. 1.

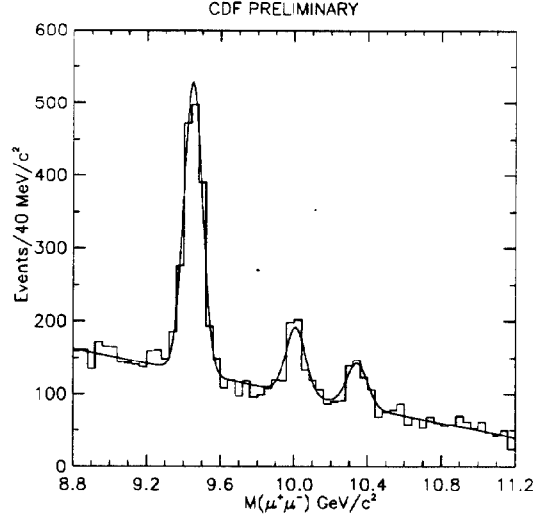


Fig. 1. Invariant mass distribution for $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$.

1.2. Acceptance and other efficiencies

The geometric and kinematic acceptances for $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S) \rightarrow \mu^+\mu^-$ were evaluated by a dimuon event generator that produces Υ 's with flat P_t and y distributions. The generated events were processed with the full detector simulation and the same reconstruction used for the data. The acceptances are P_t and y dependent and are very similar for the three different states. To verify that the acceptance is independent of the kinematic distribution of generated events, the acceptance calculation was repeated for the $\Upsilon(1S)$ state using a parton level generator¹ which provides on an event by event basis the four momentum of various bottomonium states decaying to $\Upsilon(1S)$. This generator together with the CLEO decay table was used to obtain the theoretical predictions shown in Figures 2 and 3.

Various efficiency corrections are required for the Υ cross section calculations. The Level 1 and Level 2 trigger efficiencies for each muon are increasing functions

of P_t , reaching a plateau of 92% above 3.1 GeV/c. The Level 3 tracking efficiency is $92 \pm 2\%$. The total trigger efficiency for each dimuon event is taken to be the product of the Level 1 and Level 2 efficiencies for each muon and the Level 3 efficiency for the event. The offline CTC track reconstruction efficiency is $(97.8 \pm 1.4)\%$ and the muon reconstruction efficiency is $(96 \pm 1.4)\%$ for each dimuon event. The matching cut on the difference between the muon chamber track and the extrapolated CTC track is $(98.7 \pm 0.2)\%$ efficient.

2. Differential and total cross sections

The acceptance and efficiency corrected Υ cross sections are displayed in Figures 2 and 3 as functions of P_t . The vertical error bars are from statistical fluctuations in the number of counts (background fluctuations included) and the P_t -dependent systematic uncertainties added in quadrature. The signal and background contributions have been determined independently in the P_t bins shown in the differential cross section plots by fitting the dimuon mass distribution in each bin to a gaussian plus a first degree polynomial.

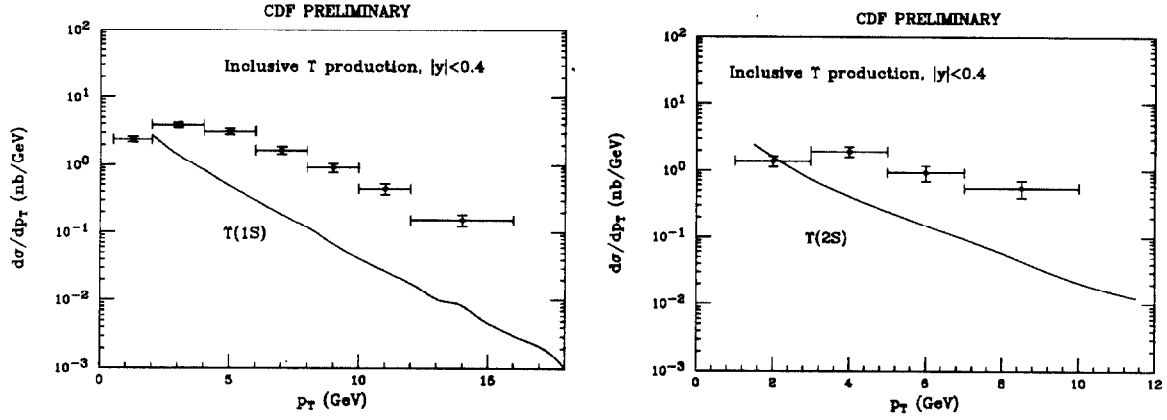


Fig. 2. $\Upsilon(1S)$ and $\Upsilon(2S)$ differential cross section for $|y| < 0.4$ compared to the theoretical prediction. Error bars include statistical error and P_T dependent systematic error. There is also a common systematic error of 15%(22%) for the $\Upsilon(1S)(\Upsilon(2S))$ not shown. The theoretical curves are leading order and were generated using MRSDO PDF with scale $\mu^2 = P_t^2 + m_\Upsilon^2$. Production and decay of higher bottomonium states are included.

The integrated cross section results are:

$$\begin{aligned} \sigma(\bar{p}p \rightarrow \Upsilon(1S), |y| < 0.4, P_t > 0.5 \text{ GeV/c}) &= 23.48 \pm 0.99 \text{ (stat)} \pm 2.80 \text{ (sys) nb} \\ \sigma(\bar{p}p \rightarrow \Upsilon(2S), |y| < 0.4, P_t > 1.0 \text{ GeV/c}) &= 10.07 \pm 1.01 \text{ (stat)} \pm 1.99 \text{ (sys) nb} \\ \sigma(\bar{p}p \rightarrow \Upsilon(3S), |y| < 0.4, P_t > 1.0 \text{ GeV/c}) &= 4.79 \pm 0.64 \text{ (stat)} \pm 0.72 \text{ (sys) nb.} \end{aligned}$$

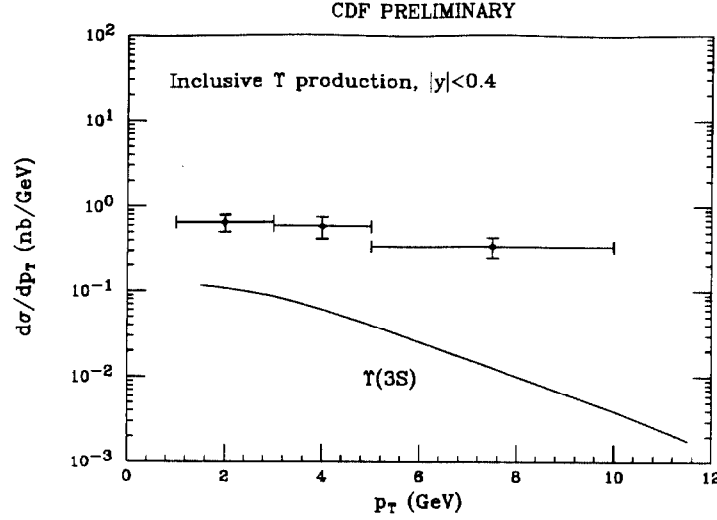


Fig. 3. $\Upsilon(3S)$ differential cross section for $|y| < 0.4$ compared to the theoretical prediction. Error bars include statistical error and P_T dependent systematic error. There is also a common systematic error of 18% not shown. The theoretical curves are leading order and were generated using MRSD0 PDF with scale $\mu^2 = P_t^2 + m_\Upsilon^2$.

The systematic errors for the total cross section measurements arise from the trigger efficiency (4-5%), from the acceptance model (10%), from the luminosity determination (3.6%) and from the various reconstruction efficiencies (2.8%). We have an additional systematic from the uncertainty of the branching ratios of $\Upsilon \rightarrow \mu^+ \mu^-$, which is 2.4%, 16% and 9.4% for the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ respectively. Total cross sections in the range $|y| < 0.4$ can be calculated at LO QCD.² Use of MRSD0 PDF with scale $\mu^2 = m_\Upsilon^2$ yields 4.2, 2.5 and 0.12 nb for the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ respectively.¹ These results include the production and decay of $\chi_b(1P)$ and $\chi_b(2P)$ states, which are found to dominate the rate of $\Upsilon(1S)$ and $\Upsilon(2S)$ respectively. No $\chi_b(3P)$ state has been observed at present, and therefore its possible contribution to $\Upsilon(3S)$ is not included. Our measurements are a factor of 4-6 higher than the theoretical prediction for the $\Upsilon(1S)$ and $\Upsilon(2S)$ states, and by a factor of 40 for the $\Upsilon(3S)$ state. While a factor 4-6 can be partly accommodated by the inclusion of higher order corrections and possible new production mechanisms,⁴ the big discrepancy for the $\Upsilon(3S)$ state suggests that there are additional χ_b states below the $B\bar{B}$ threshold that contribute significantly to the $\Upsilon(3S)$ production.

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